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Utilization of biodiesel waste as a renewable resource for activated carbon: Application to environmental problems

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ABSTRACT

Stepping into the new globalized and paradigm shifted era, a huge revolution has been undergone by the oil palm industry. From a humble source of the edible oil, today oil palm has demonstrated a wide variety of uses, almost by every part of its plant. With the price of the crude petroleum hitting record height every other day, the feasibility of palm oil and oil palm biomass as renewable substitutes for the production of biodiesel has been proposed. Lately, its development has received various criticisms, mainly hinges on the huge generation of solid residues which are currently no profitable use. In view of the aforementioned reason, this paper presents a state-of-the-art review of oil palm industry, its fundamental background studies, propagation and industrial applications. Moreover, the recent developments on the preparation of activated carbons from oil palm waste, its major challenges together with the future expectation are summarized and discussed. Conclusively, the expansion of oil palm waste in the field of adsorption science represents a potentially viable and powerful tool, leading to the superior improvement of pollution control and environmental conservation.

Contents

1. Introduction

Concern about environmental protection has increased over the years from a global viewpoint. Today, rapidly changing technologies, industrial products and practices generate waste that if improperly managed, could threaten public health and the environment [1]. Undoubtedly, the agricultural waste biomass is currently one of the most challenging topics, which gained extensive stern consideration during the past decades [2]. In the above perspective, oil palm is rated top, with an annual fruit crop production of 36.90 million tons, corresponding to 35.90% of the total edible oil in the world [3]. With the price of crude petroleum oil in the world market escalating to unprecedented height due to the political instabilities in many oil-exporting countries and diminishing oil reserves in the world, Malaysia exported a record of 9.2 million tons of palm oil (65% of global palm oil exports) in 2007, contributing RM14.42 billion (75.1%) towards the total export revenue of the country [4].

With the increasing trend of the world's demand for oils and fats, the amount of biomass produced by an oil palm tree, inclusive of the oil and lignocellulosic materials is on an average of 231.5 kg dry weight/year [5]. This has attested the utilization of oil palm as a renewable source of energy or feedstock for a large variety of

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downstream products. Its potentiality is further enhanced and facilitated by the fact that oil constitutes only 10% of the palm production, while the biomass constitutes rest 90% [3]. Over the years, a number of studies and researches have been conducted for the conversion of oil palm biomass into the high value-added and useful income-generating products [6].

Of major interest, biodiesel, manufactured by the esterification of renewable oils, fats and fatty acids [7], has demonstrated large support and encouragement, owing to its ability and feasibility in fulfilling the pressing need for renewable energy [8]. Unfortunately, in terms of its sustainability, the conversion of biodiesel is currently gaining extensive criticisms: extinction of animals, deforestation, food versus fuel dispute and solid residues generation. Recognizing numerous challenges associated with its economical unavailability and prevention of edible oil demand [7,9,10], the successful integration of activated carbons has reflected the diversification of palm oil waste, and contributed effectively towards the stability and sustainable development of the oil palm industry. The review attempts to summarize the origin, development and potential applications of the oil palm industry. The present work is aimed at providing a concise and up-to-date picture of the present status of oil palm industry enhancing sustainable and renewable energy. The prospects towards the utilization of oil palm waste (biodiesel waste) as renewable sources (for the preparation of activated carbons) together with its comprehensive literature has been highlighted and outlined, to familiarize the reader with pertinent information regarding oil palm industry.

2. The origin and critical properties of the oil palm

Despite having the distinction of contributing to the historical development of science and global industries, the appearance and economic value of oil palm was still relatively unfamiliar and unknown during the beginning of the 21st century [11]. Generally, oil palm is native to the West and Central Africa, whose botanical classification, *Elaeis guineensis*, *Jacq*., is derived from the Greek elaion (oil), and the specific name of *guineensis* is an indication of its origin from the equatorial Guinea coast [3,12]. The monocotyledon belonging to tropical perennial plant [13] comprises two species of the Arecaceae (palmae family) [14], and its mature trees that are unbranched and single-stemmed can grow to a height of 20–30 m [15], with an economic life span of 25–30 years [16].

Oil palm leaves are pinnate, reach between 3 and 5 m long and its flowers are produced in dense clusters; each individual flower is small, with three sepals and three petals [17]. The fleshy orange reddish colored fruits grow in large and tight female bunches, each weighing as much as 10–40 kg, containing up to 2000 fruitlets (black when young) [15,18]. It usually requires a 5–6 month period to mature from pollination, comprising an oily, fleshy outer layer (exocarp), with an outer pulp containing palm oil (mesocarp) and a hard shell enclosing the kernel (endosperm) which contains oil and carbohydrate reserves for the embryo (Fig. 1) [19,20]. Table 1 lists the dry weight composition of oil palm mesocarp and its fresh ripe fruit.

Typically, oil palm fruit is harvested after 3 years from planting, with its maximum yield in the 12th or 13th year, and continuously declines till the end of the 25th year (replanting) [18]. Being the first commercial commodity, palm oil has been extensively utilized in food and beverages (oils, margarines, bread, mayonnaise, industrial frying, chocolate, feeds, ice cream and cookies), manufacturing (soaps, lubricants, detergents, plastics, cosmetics and rubber), steel, textile, oleochemical, pharmaceutical as well as the fuel industries [21]. Historically, oil palm has been initially cultivated by the Portuguese in the State of Bahia and later in the State of Pará, Brazil in the 17th century [22]. The earliest illustration has been described by Nicholaas Jacquin in 1763 (Fig. 2) [23]. Generally, the propagation of oil palm did not occur until the beginning of the Industrial Revolution, which fuelled with a wide variety of scientific investigations and inventions [24], the seeds were brought by the Dutch to Indonesia, resulting in the four seedlings planted in Bogor, Indonesia in 1848 [25]. In Malaysia, oil palm was firstly planted as an ornamental, and the commercial

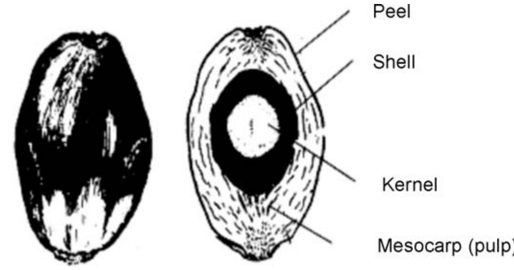

Fig. 1. Fresh oil palm fruit image with its longitudinal section [20].

Table 1
The dry weight composition of mesocarp and fresh ripe fruit for the oil palm [4].

Fruit	Dry weight (%)	Mesocarp	Dry weight (%)
Palm oil	29	Palm oil	46–50
Water	27	Palm oil (dry basis)	77–81
Residue	8	Moisture	36–40
Shell	30	Non-fatty solids	13–15
Kernel	6		

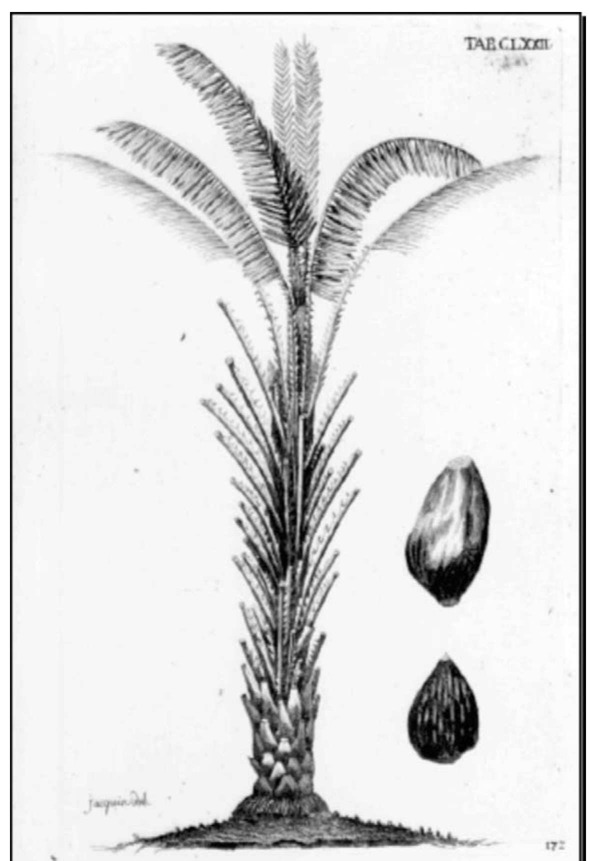

Fig. 2. The earliest illustration of the oil palm [23].

Table 2
Quantity and types of oil palm biomass generated per year [41].

Type of biomass	Quantity/year (MnT)
Empty fruit bunch (EFB)	15.8
Fronds	12.9
Mesocarp fiber (MF)	9.6
Trunk	8.2
Shell	4.7

planting was started at Tennamaran Estate, Selangor in 1917 [26,27].

3. The rapid propagation and development of palm oil industries

Over the past few decades, palm oil has been one of the most successful stories of the Malaysian agricultural sector [28]. In the world trade market, Malaysia is presently the major key player, accounting approximately 50% and 58%, the leading producer and exporter of the palm oil [29,30]. Concomitantantly blessed with plentiful abundant natural resources and a climate conducive to commercial cultivation of crops [31], located in the wet and humid tropics, in bands of land extending 10° to the north and also to the south of the Equator [4,32], with a fair amount of sunshine, a hot climate coupled with temperature averages of 25 °C, and a high rainfall rate (2.000 mm of rain) well distributed throughout the year [33], Malaysia poses an ideal and substantial potential for the dense tropical forest growth and agricultural vegetation.

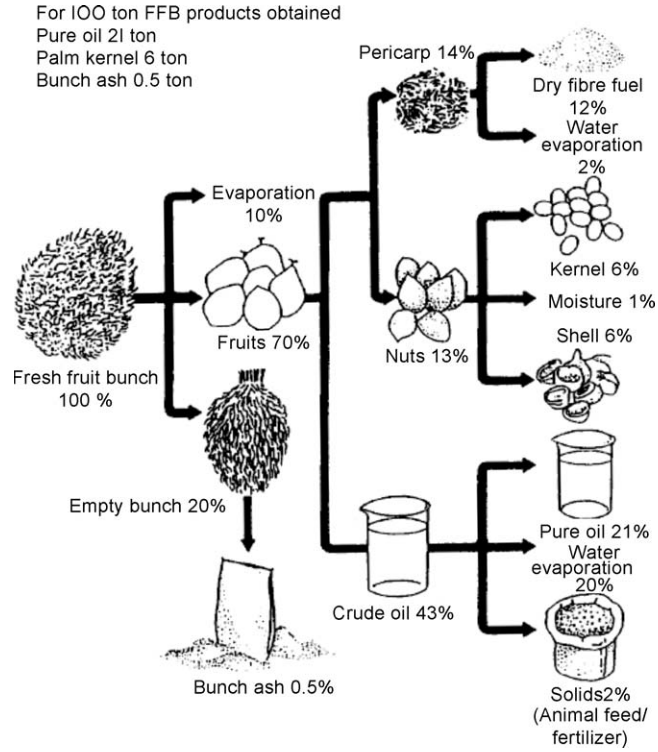

Fig. 3. Typical composition chart of the palm fruit production processes [120].

Table 3
Recent researches of the preparation of activated carbons from various oil palm wastes.

Precursor	Adsorbate	BET surface area (m^2/g)	Micropore surface area (m^2/g)	Porosity (%)	Total pore volume (cm^3/g)	Maximum q_e (mg/g)	Maximum monolayer adsorption capacity (mg/g)	Reference
Oil palm shell, oil palm fibers	Nitrogen dioxide, sulfur dioxide	1100.00	–	63.6	0.28	219.00	–	[19]
Oil palm fibers	Methylene blue	–	–	–	–	213.81	400.00	[91]
Oil palm shell	Phenol	1182.76	828.43	–	0.69	–	–	[92]
Oil palm shell	Phenol	988.00	715.00	–	–	166.0	–	[93]
Oil palm shell	Methylene blue	–	–	–	–	248.16	303.03	[94]
Palm empty fruit bunches	2,4,6-Trichlorophenol	–	–	–	–	210.79	500.00	[95]
Oil palm shell	Methylene blue	596.20	–	–	0.34	240.94	243.90	[96]
Oil palm wood	Methylene blue	1084.00	931.60	–	–	90.90	–	[97]
Palm empty fruit bunches	2,4-Dichlorophenol	–	–	–	–	22.2	27.25	[98]
Oil palm shell	Hydrogen sulphide	1148.00	–	56.3	0.25	203.00	–	[99]
Oil palm shell	Nitrogen oxide	635.00	–	–	–	–	–	[100]
Oil palm shell	Phenol	1183.00	–	–	0.69	319.00	–	[101]
Oil palm fibers	Methylene blue	1354.00	–	–	0.78	276.00	277.78	[102]
Oil palm shell	Nitrogen	519.00	457.00	–	0.22	–	–	[103]
Oil palm shell	Sulfur dioxide	1563.00	772.00	72.90	–	19.31	–	[104]
Oil palm shell	Nitrogen	1400	–	–	–	–	–	[105]
Oil palm shell	Nitrogen	1200.00	–	–	0.60	–	–	[106]
Oil palm shell	Nitrogen dioxide	1350.00	925.00	17.2	0.69	–	–	[83]
Oil palm shell	Sulfur dioxide	1366.00	985.00	66.00	–	76.30	–	[107]
Oil palm shell	Carbon dioxide	1366.00	958.00	–	0.96	–	–	[108]
Oil palm shell	Sulfur dioxide	1366.00	958.00	–	–	76.00	–	[58]
Oil palm shell	Sulfur dioxide	1563.00	772.00	63.30	–	76.00	–	[109]
Oil palm stones	Nitrogen	820.00	575.00	58.3	0.30	–	–	[110]
Oil palm stones	Nitrogen	1952.00	812.00	76.2	0.96	–	–	[111]
Oil palm stones	Nitrogen	469.10	225.60	46.9	0.21	–	–	[112]
Oil palm stones	Ammonia	1837.00	798.00	76.20	1.27	132.00	–	[81]
Oil palm shell	Nitrogen dioxide	1452.00	690.00	–	0.78	76.00	–	[113]
Oil palm stones	Nitrogen dioxide	1410.00	942.00	70.70	0.71	–	–	[114]
Oil palm stones	Sulfur dioxide	1562.00	718.00	61.1	0.75	80.0	–	[115]
Oil palm fibers	Nitrogen	520.60	366.40	38.9	0.34	–	–	[116]
Oil palm stones	Nitrogen	318.00	–	24.0	–	–	–	[117]
Oil palm fibers	Nitrogen	521.00	366.00	–	0.35	–	–	[118]
Oil palm fibers	Nitric oxide	894.70	628.20	–	0.67	–	–	[119]

During the 1950s, the expansion of palm oil industry started as part of the government's diversified cautious policy from rubber to oil palm, in raising the socio-economic status of the expanding population in the country [34]. Today, its growth has been phenomenal in Malaysia, replacing Nigeria as the chief producer since 1971 [35]. In 1960, Malaysia's crude palm oil production was recorded as 2.6 million tons [36] and in 1980 and 1997, the production has risen to 2.67 and 9 million tons respectively [37]. Maintaining the top ranking as the largest supplier, the annual oil production figures in 1998 and 1999 were individually achieved as 8.3 and 10.6 million tons respectively [13]. By illustrating the steady growth production rate, the annual generations in 2004, 2005, 2006 and 2007 were designated as 15.2, 14.96, 16.5 and 15.8 million tons respectively [38]. By the year 2008 and 2030, the annual production is predicted to be further strengthened to 16.3 and 50 million tons respectively [37,39], underlying the exponential growth rate of population and social civilization, and development of industry and technology as its key drivers [40].

Simultaneously, from merely 54,000 hectares in the early 1960s, the oil palm plantation area has gradually increased to 1.8, 3.5, 3.8, 4.2 and 4.3 million hectares in 1990, 2001, 2003, 2005 and 2007 respectively [41], representing 56% of the total agricultural land and 11.75% of the country's total land area [3]. By 2008 and 2020, the figures are expected to expand, occupying 4.3 and 5.1 million hectares of estates respectively [42,43], managed by the publicly listed companies, smaller independent estates, independent smaller holders and government smallholder settler schemes [29] around the Peninsular Malaysia and the east states of Sabah and Sarawak [44]. Accordingly, the plantations are fulfilled with a density of 148 palms per hectare, and an oil palm tree usually occupies 0.0068 hectares of land, and 5 tons of oil per year was yielded per hectare of palms [4]. In South East Asia (SEA), Indonesia is on the right tract to switch its government policy from the industrial to the agricultural order economy, after the economic turmoil in July 1997. For the last 3 years, a lot of giant palm oil plantations and processing industries have been widely developed in the islands of Sumatra, Kalimantan and Sulawesi [28]. Elsewhere, oil palm has been documented as replacing forest in southern Thailand [45], Myanmar [46], Papua New Guinea [47], Latin America [48], Nigeria and Ivory Coast [13].

4. Recycling of oil palm waste and resources for activated carbons production

In recent years, the recycling and reservation of the agricultural biomass as an effective option for the provision of sustainable resources has received considerable increased concern all around the globe [3]. In step with the projected growth of the cultivation of oil palm, the supply of world oil palm biomass and its processing byproducts are found to be 7 times of the availability of natural timber [49], generating more than 184.6 million tons of biomass per year [50]. In Malaysia in particular, an annual estimation of 73.74 million tons of biomass residues is expected to be contributed, in the form of palm leaves, palm fronds, palm trunks, empty fruit bunches, palm shells, palm fibers and palm stones [51,52].

From each bunch of the fresh palm fruit, approximately 21% of palm oil, 6–7% of palm kernels, 14–15% of palm fibers, 6–7% of palm shells and 23% of empty fruit bunches can be obtained [35]. In this respect, empty fruit bunches and palm fibers, as the major components of the flourishing palm oil industry's biosolid wastes, were reported containing 42% C, 0.8% N, 0.06% P, 2.4% K and 0.2% Mg, and 6.6% P, 25% K and 7% Ca [53]. Traditionally, empty fruit bunches are incinerated for its ash, as a good fertilizer or soil conditioner (due to its high organic and nutrient content beneficial to the crops) [54], and palm fibers are found to be ideal for the making of mattresses, seats and insulations [55].

Oil palm shells as the energy sources for power generation (heat and electricity) via combustion [56], or chemical feedstock for solid (char), liquid (aqueous and tar fractions) and gaseous products

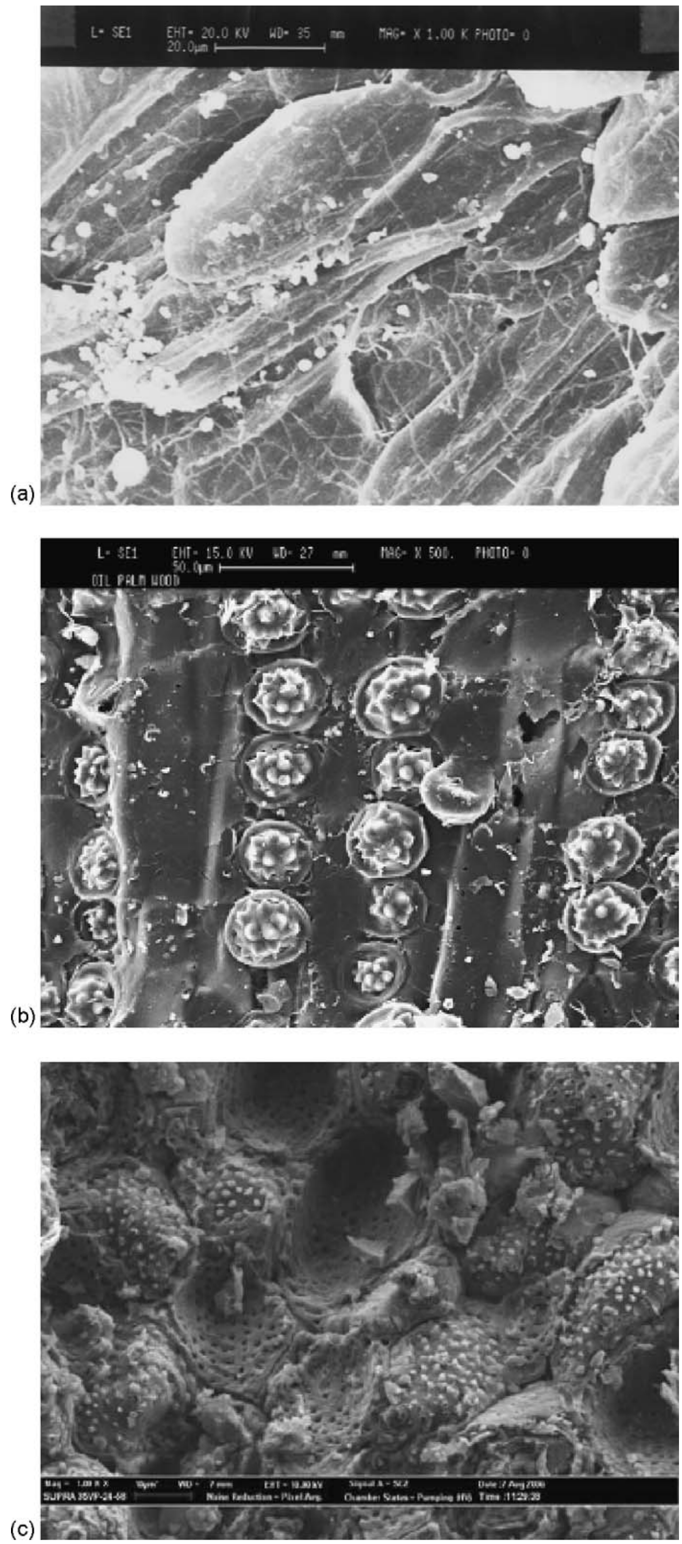

Fig. 4. Scanning electron micrographs (SEM) of the raw palm stone (1000×) (a) [117], oil palm wood (500×) (b) [97], oil palm shell (1000×) (c) [96] and oil palm fiber (4000×) (d) [116].

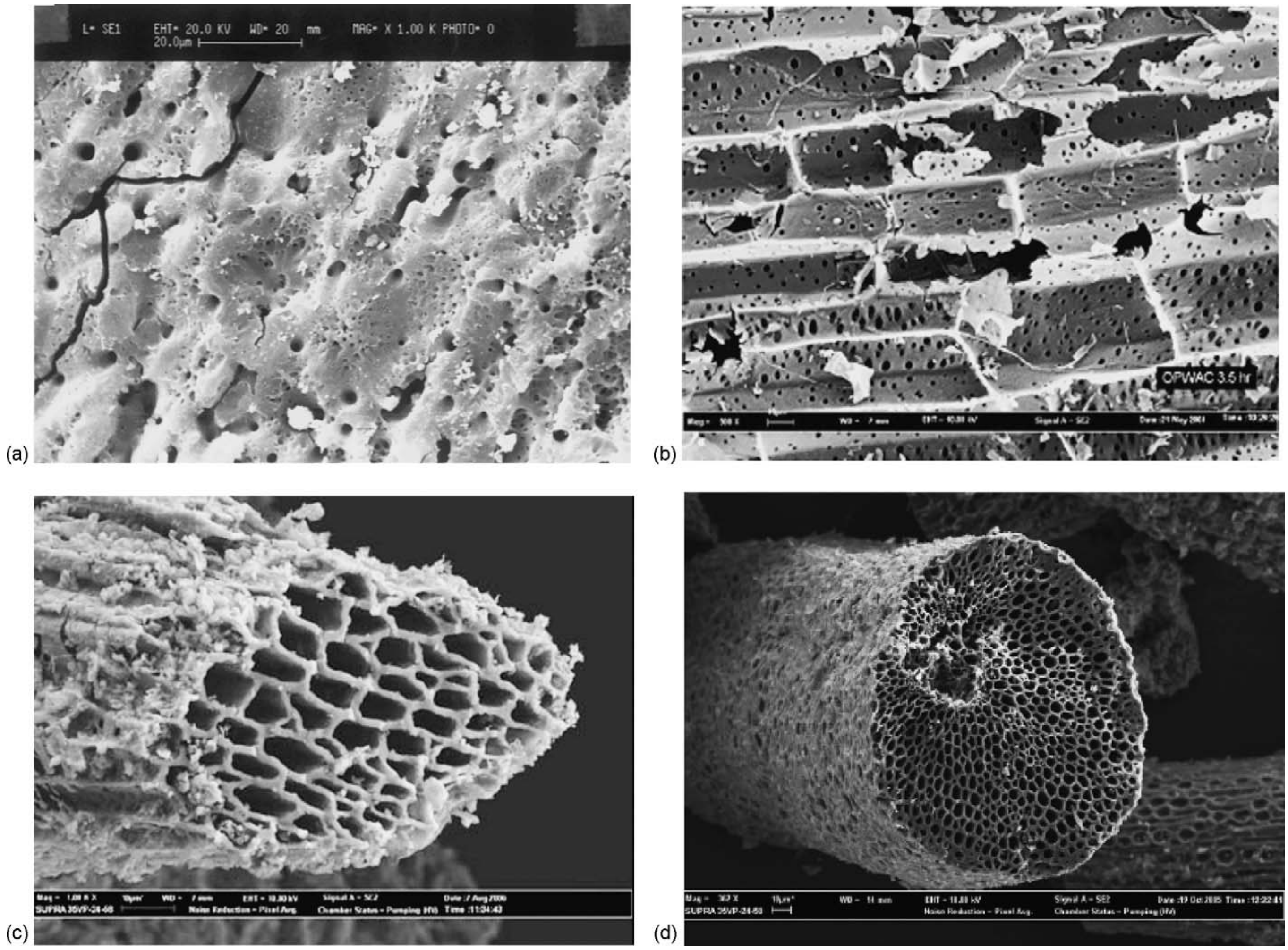

Fig. 5. Scanning electron micrographs (SEM) of the activated carbons prepared from raw palm stone (1000×) (a) [117], oil palm wood (500×) (b) [97], oil palm shell (1000×) (c) [96] and oil palm fiber (362×) (d) [102].

[57], are generated at 2.4 million tons annually in Malaysia [58]. In other cases, oil palm trunks, which are available throughout the year, are utilized as timber for manufacturing pulp, paper and fiber board in the wood based industries [5]. Meanwhile, a large fraction of oil palm fronds are left rotting between the rows of palm trees, mainly for soil conservation, erosion control and ultimately the long-term benefit of nutrient recycling [59], whereas oil palm leaves and stone are implemented for thatching, shed-making, fencing and as construction materials, protecting the tops of the mud walls [15,40]. Table 2 summarizes the types and quantity of oil palm biomass generated per year and Fig. 3 displays a typical composition chart of the palm fruit production processes.

On the contrary, the application has exhibited its difficulties and limitations, and the presence of even a small amount of oil may lead to the contamination of the paper making end product, thereby resulting in a detrimental effect on the quality [4]. Increasingly, the availability of oil palm biomass all over the year is much larger than the amount needed, allowing continuous operation of the process [3]. Realizing the above complications, the urgency of transforming the residue into a more valuable end product has been promulgated. A promising option is converting them into a prospective precursor for the preparation of activated carbon [52]. Of late, adsorption is recognized as an efficient, versatile and most widely used technique in the wastewater treatment processes [60,61], especially in developing countries the issue being highly intense and touching [62], mainly hinges on its simplicity, ease of handling, economical viability, technical feasibility and social acceptancee [63].

During recent decades, a notable trend in the development of activated carbon, an adsorbent with its large porous surface area, controllable pore structure, thermostability and low acid/

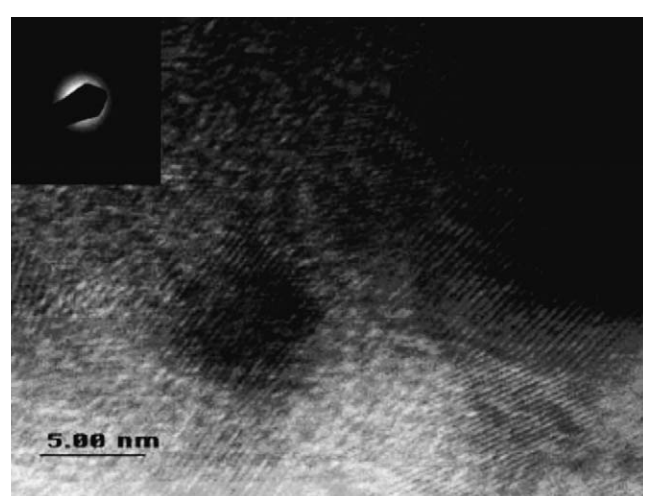

Fig. 6. Transmission electron micrographs (TEM) and the corresponding diffraction pattern of the palm shell activated carbon [107].

base reactivity [64] has been witnessed [65], owing to its superior ability in air pollution control [66], solvent recovery [67], food processing [68], chemical and pharmaceutical industries [69], wastewater treatment (dyes, heavy metals, detergents, herbicides, pesticides and polyaromatic hydrocarbons) [70,71,72], metal recovery [73], catalysis [74] as well as the improvement of odor and taste [75]. Despite its prolific use in adsorption processes, the biggest barrier of its application by the industries is the cost-prohibitive adsorbent and difficulties associated with regeneration [76]. This has exerted a growing research to investigate the feasibility and suitability of natural, renewable and low-cost materials as alternative precursors in the water pollution control, remediation and decontamination processes (palm shell, pall fiber, palm stone, bamboo dust, peat, chitosan, lignite, fungi, moss, bark husk, chitin, coir pith, maize cob, pinewood sawdust, rice husk, sugar cane bagasse, tea leaves, and sago waste) [77,78].

Additionally, the anxiety of the enormous waste production and resource preservation has focused greatest attention towards the recovery of input resources, offering new opportunities for the diversification of oil palm products [41]. The results are very promising, attributing to the relatively high fixed carbon and volatile matters content, low ash content, and high density or mechanical strengths of the precursors, associated with the inherent highly porous structures within the carbon matrix [19]. Table 3 lists recent researches of the preparation of activated carbons from various oil palm wastes. The findings will provide a twofold advantage with respect to environmental management. First, huge volume of oil palm waste could be partly reduced, converted to useful, value-added adsorbents, and second, the low-cost adsorbent, if developed, may overcome the wastewater pollution at a reasonable cost [79,80], solving part of the agricultural wastes and wastewater treatment problem in Malaysia.

The scanning electron micrographs (SEM) of the oil palm waste and the prepared activated carbons are illustrated in Figs. 4 and 5 respectively. These textural structures may consist of well developed graphite layers, and the spaces between the carbon layer planes and the gaps between the stacks will form an interconnected network of slit-shaped pores, ultimately accommodate the adsorbate molecules during the adsorption process [81]. Hereby, its surface chemistry is governed by a small amount of heteroatoms (hydrogen, oxygen, nitrogen, sulfur and phosphorus), bonded at the edges of aromatic sheets, or incorporated within the carbon matrix forming heterocyclic ring systems [82]. Fig. 6 shows the bright field transmission electron micrograph (TEM) of the oil palm shell activated carbon. The existence of diffraction rings and irregular structures in various orientations, indicating the amorphous patterns of the activated carbon, and the gaps between the carbon layers (parallel lines) represent the slit-shaped micropores, of mostly less than 2 nm [83].

Meanwhile, the physical, chemical and porous structures of the prepared activated carbons are described by the Fourier Transformed Infra-red (FTIR) (Fig. 7) and X-ray diffraction (XRD) (Fig. 8) images, illustrating the presence of bands: 3608 cm^{-1}, free O–H, stretching vibration in hydroxyl groups (assignment range 3635–3610 cm^{-1}); 1725 cm^{-1}, C═O stretching vibration in carboxylic acids or isolated carbonyl groups (1850–1650 cm^{-1}); 1642 cm^{-1}, C═O stretching vibration in quinines or carboxylic anhydrides (1610–1650 cm^{-1}); 1506 cm^{-1}, C═C stretching vibration in aromatic rings (around 1600 or 1500 cm^{-1}); 1219 cm^{-1}, C–OH stretching vibration in alcohols (1200–1257 cm^{-1}); 695 cm^{-1}, C–H out-of-plane bending in benzene derivatives (900–600 cm^{-1}) and 1204 cm^{-1}, C–O–C stretching in ethers or ether bridges between rings. Tables 4 and 5 summarize the proximate analysis for the oil palm waste and the prepared activated carbons.

5. Current trend and major challenges

The world is currently facing the worst energy crisis in its entire history. For the past two decades, the search for renewable and environmental friendly alternative energy has been carried out extensively [42]. Realizing the urgency of reducing emissions and simultaneously catering to the needs of industries [3], global palm oil production is increasing by 9% every year, prompted largely by the expanding biofuel markets in the European Union [84] and by the food demand in Indonesia, India and China [85]. In Malaysia, more than 2.8 million hectares of land is under oil palm cultivation [33] and it was estimated that a total of 42 million tons of fresh empty fruit bunches are produced annually, translating to around 17 million tons of biomass waste. For low-pressure systems with a conversion rate of 2.5 kg of palm oil waste per kWh, potentially 7000 GWh of energy could be generated [86]. With a total amount of 31,500 million m^3 palm oil mill effluent (POME) produced from

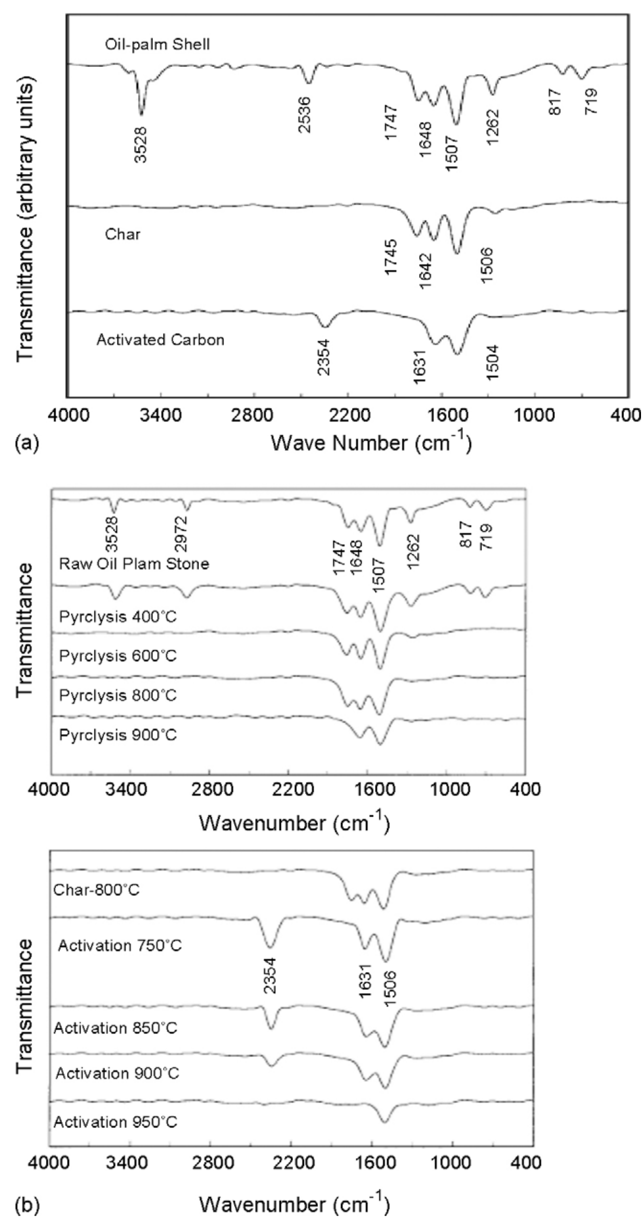

Fig. 7. Fourier Transformed Infra-red (FTIR) images for oil palm shells (a) [107], oil palm stones (b) [110], oil palm fibers (c) [102], and oil palm woods (d) [97] activated carbons.

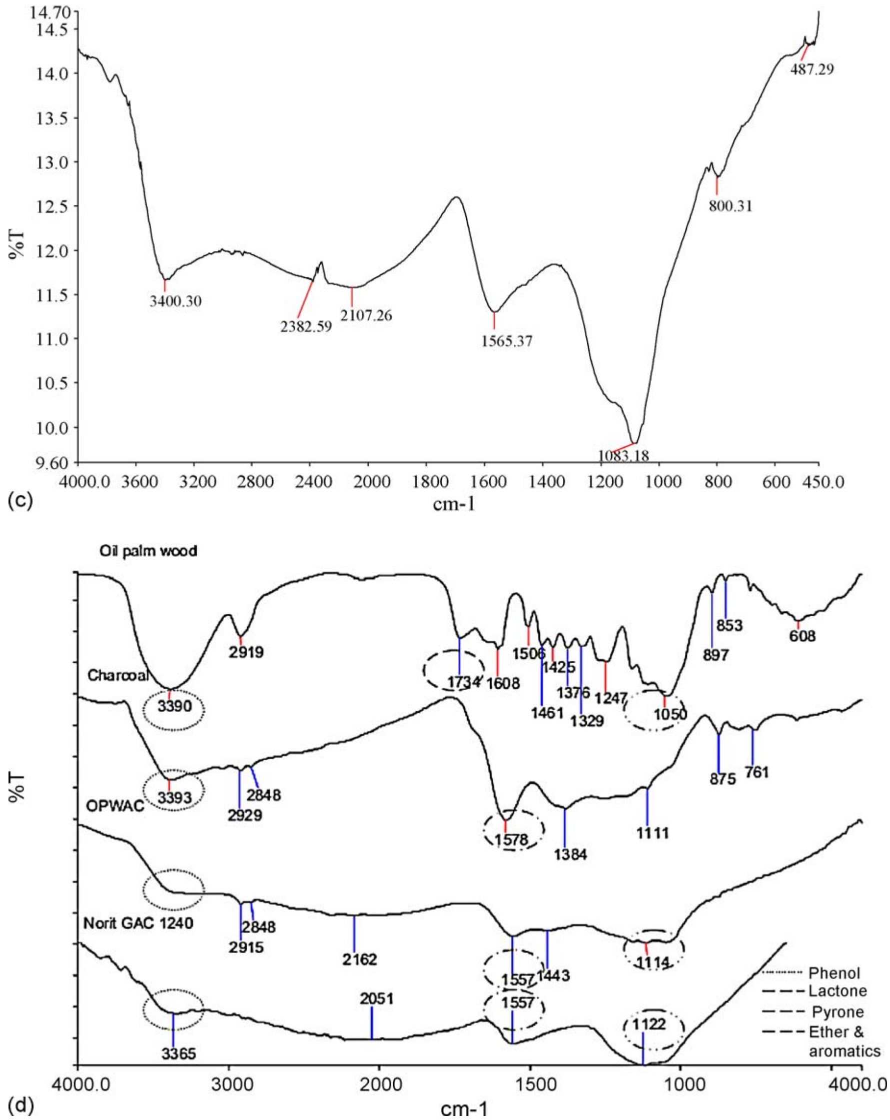

Fig. 7. (*Continued*).

palm oil mill processing per year, 1587 GW hours of energy with a capacity of 177 MW is predicted to be obtained (Table 6) [33].

Lately, environmental consideration and public concern are increasingly becoming more important, striving towards the quality and environmental conservation through sustainable development and cleaner technology approach. In line with achieving the status of an industrialised nation as part of the Vision 2020, a supportive environment to incorporate energy conservation and energy efficiency measures has been developed [4]. Over the years, oil palm industry has cooperated well with the World Wide Fund (WWF) for nature's global initiative towards more sustainable palm oil production [2], contributed towards various sound practices in minimizing the negative environmental burdens by the adoption of better management practices (BMPs) (standard operational practices) and implementation of zero carbon emission technique [87,88] for mitigation of the global warming effect and overcoming the dwindling reserves of fossil fuel.

Increasingly, there are recognition worldwide technological advances and innovations in natural adsorbents production of the necessity to reconcile agriculture practices with the need for environmental conservation, ensuring the long-term agricultural operations and sustainability of the cropping systems [29]. Consequently, numerous research and development efforts have been undertaken to utilize oil palm wastes contemplated mainly on the production of activated carbons [6,89]. Although there has been some successful industrial-scale production of renewable resources from biomass, generally the industry is still facing various challenges, the availability of economically viable technology, sophisticated and sustainable natural resources management, and proper market strategies under competitive energy markets. Amidst these challenges, the development and implementation of suitable policies by the local policy-makers is still the single and most important factor which determines a successful utilization of renewable resources [3].

Recently, the enforcement of environmental rules and regulations concerning various contaminants from agricultural waste streams by regulatory agencies are becoming more stringent and restrictive [90], and inevitably affect the waste disposal practice of the palm oil industry [53]. In Malaysia, the enactment of the Environmental Quality Act of 1974 and the subsequent formation of the Department of Environment in 1976 was amended in 1985 to include the submission of Environmental Impact Assessment (EIA) reports on proposed development programmes to the

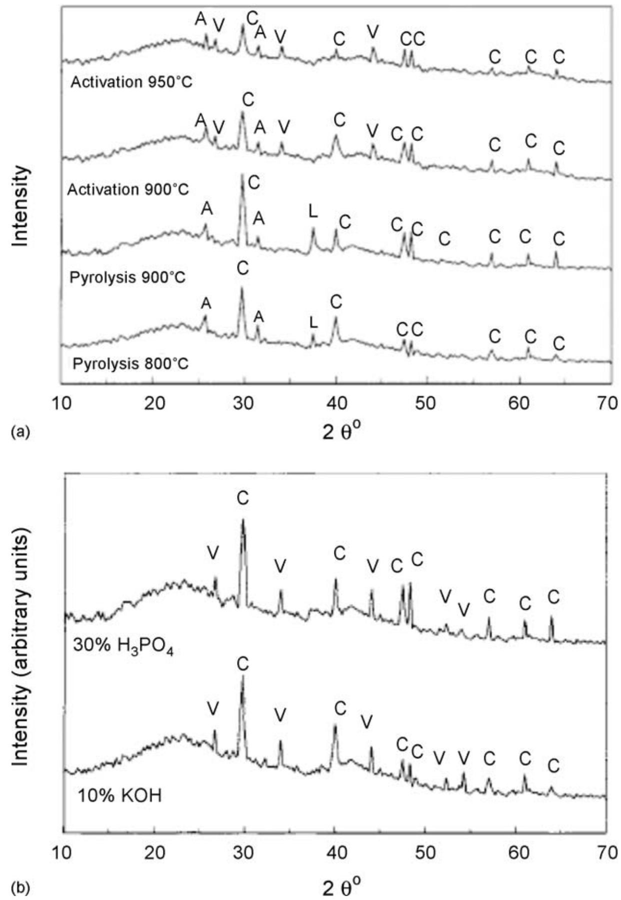

Fig. 8. X-ray diffraction (XRD) images for oil palm stones (a) [110] and oil palm shells (b) [113] activated carbons.

Table 4
Proximate analysis for the oil palm waste.

Raw material	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Reference
Oil palm shell	–	80.80	18.30	0.90	[19]
Oil palm fibers		77.60	19.80	2.60	
Oil palm shell	–	77.60	19.80	2.60	[83]
Oil palm wood	11.83	76.58	9.63	1.95	[97]
Oil palm shell	4.82	65.85	28.36	0.97	[103]
Oil palm shell	–	77.60	19.80	2.60	[108]
Oil palm stones	5.30	76.50	16.40	1.80	[110]
Oil palm stones	–	79.70	18.30	2.00	[111]
Oil palm stones	–	80.80	17.30	1.90	[112]
Oil palm fibers	0.24	80.57	18.23	0.96	[116]
Oil palm stones	5.30	76.50	16.40	1.80	[117]
Oil palm fibers	0.24	80.57	18.23	0.96	[118]

Table 5
Proximate analysis for the oil palm waste activated carbons.

Precursor	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Reference
Oil palm shell	0	1.00	89.50	9.50	[83]
Oil palm stones	0	2.20	88.96	9.20	
Oil palm wood	9.50	18.0	68.30	4.30	[97]
Oil palm shell	–	4.50	91.90	3.60	[99]
Oil palm shell	–	0.70	89.40	9.90	[108]
Oil palm shell	–	2.60	90.0	7.40	[109]
Oil palm stones	–	2.70	91.00	6.30	[111]
Oil palm stones	–	6.20	84.60	9.20	[112]
Oil palm fibers	0.11	4.08	87.13	8.68	[116]
Oil palm stones	0.20	2.20	88.50	9.10	[117]
Oil palm fibers	0.11	4.08	87.13	8.68	[118]
Oil palm fibers	0.20	5.43	89.72	4.65	[119]

Table 6
Energy database for the oil palm biomass [33].

Palm waste	Heat value (kJ/kg)
Empty fruit bunches	18,795
Fibre	19,055
Shell	20,093
Palm kernel cake	18,884
Nut	24,545
Crude palm oil	39,360
Kernel oil	38,025
Liquor from (EFB)	20,748
Palm oil mill effluent (POME)	16,992
Trunk	17,471
Petiole	15,719
Root	15,548

Department of Environment for approval [31]. Ultimately, the integration of the suitable policy with compatible technology investigations is a key challenge for the race to the end line.

6. Conclusion

The environmental pollution and diminishing supply of fossil fuels are the key factors leading to search for the alternative sources of energy. Today, the world's accessibility to oil reserves is gradually depleting, driving towards the overwhelming researches dealing with biodiesel production (mainly from oil palm or palm oil biomass). The past 10 years has seen a developing interest in the preparation of low-cost adsorbents as alternatives in water and wastewater treatment processes. To date, the limited success of adsorbents in field applications has raised apprehensions over the use of biodiesel waste in the preparation of activated carbons as a measure to the drinking water treatment. The evolution has turned from an interesting alternative approach into a powerful standard technique by offering a number of advantages: better performance in terms of ulterior adsorption capacity and rate of adsorption, solving wastewaters pollution at a cost effective way and overcoming part of the agricultural wastes and problem in Malaysia. Thus, a widespread and great progress in this area can be expected in the future.

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